LP 714-37: A wide pair of ultracool dwarfs actually is a triple*

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ABSTRACT

LP 714-37 was identified by Phan-Bao et al. (2005) as one of the very few wide pairs of very low mass (VLM) stars known to date, with a separation of 33 AU. Here we present adaptive optics imaging which resolves the secondary of the wide pair into a tighter binary, with a projected angular separation of 0.36″, or 7 AU. The estimated spectral types of LP 714-37B and LP 714-37C are M8.0 and M8.5. We discuss the implications of this finding for brown dwarf formation scenarios.

Subject headings: stars: low mass, brown dwarfs — binaries: visual — stars: individual (LP 714-37, DENIS-P J0410-1251)

1. Introduction

Binary systems offer the only practical opportunity to measure accurate stellar masses, and represent a powerful test of evolutionary models and star formation theories. These last aspects are particularly important for stars at the bottom of the main sequence and brown dwarfs (BDs), whose physical parameters and formation mechanism are not well known. Significant attention has recently been concentrated on binaries among ultracool dwarfs (spectral types later than M6) both in the field (Martín et al. 1999; Reid et al. 2001; Close et al. 2002, 2003; Bouy et al. 2003; Burgasser et al. 2003; Forveille et al. 2004,

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2005; Siegler et al. 2005; Liu & Leggett 2005; Law et al. 2006) and in nearby young open clusters and associations (Martín et al. 1998, 2000, 2003; Luhman 2004a; Kraus et al. 2005; Stassun et al. 2006; Bouy et al. 2006a). These surveys demonstrate that wide binary systems (semi-major axis > 15 AU) are very rare amongst ultracool dwarfs, with a frequency below 1%, while tighter binaries (semi-major axis < 15 AU) occurs in >15% of them. This well defined cutoff is not caused by disruptions during galactic dynamical encounters, which only become effective at significantly wider separations (Weinberg et al. 1987). One possible explanation lies in the ejection model (Reipurth & Clarke 2001; Bate et al. 2002) for brown dwarf formation, which describes them as failed stellar embryos, ejected from their parent gas core before they have time to accrete a larger mass. Wide binaries are not expected to survive such an ejection, and the numerical simulations of this process suggest that it only produces close binaries (separation ≤ 10 AU; Bate et al. 2002), in rough agreement with the observations. More recently however, a growing number of wide binaries (separation > 30 AU) has been detected (Luhman 2004a; Phan-Bao et al. 2005; Chauvin et al. 2004; Luhman 2005; Billères et al. 2005; Bouy et al. 2006b), suggesting that at least some VLM stars and BDs form through another process. Some of these apparent binaries, however, could be unresolved higher multiplicity systems, with a correspondingly higher total mass and binding energy. Ascertaining how many of them there are is clearly important.

In this Letter, we present adaptive optics observations of one such system, LP 714-37 (Phan-Bao et al. 2005), prompted in part by its apparently overluminous secondary. The new images do resolve that secondary into a tighter pair, and demonstrate that the system contains three VLM stars. Sec. 2 presents the observations and the data reduction, while Sec. 3. discusses the results in the context of the binary properties of wide VLM stars and BDs in general, and of the formation of LP 714-37 in particular.

2. Observations and data reduction

We observed LP 714-37 at the 3.6-meter Canada-France-Hawaii Telescope (CFHT) on 2005 October 13^{th}, using the CFHT Adaptive Optics Bonnette (AOB) and the KIR infrared camera. The AOB, also called PUEO after the sharp-visioned Hawaiian owl, is a general-purpose adaptive optics (AO) system based on F. Roddier's curvature concept (Roddier et al. 1991). It is mounted at the telescope F/8 Cassegrain focus, and cameras or other instruments are then attached to it (Arsenault et al. 1994; Rigaut et al. 1994). The atmospheric turbulence is analysed by a 19-element wavefront curvature sensor and the correction applied by a 19-electrode bimorph mirror. Modal control and continuous mode gain optimization (Gendron & Lena 1994; Rigaut et al. 1994) maximize the quality of the AO correction for

the current atmospheric turbulence and guide star magnitude, and produced well corrected images for the faint LP 714-37 system ($V = 16.5$, $I = 13.0$). For our observations a dichroic mirror diverted the visible light to the wavefront sensor while the KIR science camera (Doyon et al. 1998) recorded infrared photons. The KIR plate scale is $0.''035$ per pixel, for a total field size of $36'' \times 36''$.

We observed LP 714-37 through a K′ filter, and obtained series of five 30s exposures at each of five dither positions. The raw images were median combined to produce sky frames, which were then subtracted from the raw data. Subsequent reduction steps included flat-fielding, flagging of the bad pixels, and finally shift-and-add combinations of the corrected frames into one final image (Fig. 1) with a 12.5 min total exposure time. Analysis of this image with SExtractor (Bertin & Arnouts 1996) produced the relative astrometry and relative photometry summarized in Table 1.

3. Discussion

3.1. Physical parameters of the LP 714-37 triple system

The proper motion of the system is $\mu_\alpha = -117$ mas/yr and $\mu_\delta = -382$ mas/yr (Phan-Bao et al. 2003), and it has moved by $1.95''$ between the epoch of the DENIS image (2000.0) and our CFHT observation. Figure 2 shows no background star at the position of the system in the DENIS and 2MASS K images, demonstrating that the system is a physical triple.

Phan-Bao et al. (2005) spectroscopically classified component A as M5.5, with an estimated absolute magnitude of $M_K = 9.11$. The relative photometry listed in Table 1 therefore provides estimates of $M_K = 10.05$ for LP 714-37B and $M_K = 10.35$ for LP 714-37C. We note that the difference between the DENIS-K, 2MASS-K and K′ photometry is very small (Carpenter 2001), and completely negligible for the purpose of the present paper. Adding the flux of the three components, the absolute K-band magnitude of the system is $M_{\rm K} = 8.5$, which combines with the DENIS magnitude ($K_{\rm s} = 9.89$) to give a photometric distance of 18.9±2.6 pc. At this updated distance the projected separations between B and C, and A and the BC barycenter, are respectively of 6.8 and 36.1 AU.

We estimate approximate spectral types for components B and C from their absolute K-band magnitude (which itself scales back to the spectral type of A). A linear least-square fit to the absolute magnitudes and spectral types relation of 35 single M5.0-M9.5 dwarfs (Fig. 3), gives the following relation:

$$\mathrm{SpT} = 2.17\ M_{\rm K} - 13.9,\ \sigma = 0.68$$

where SpT is the spectral subtype, 5.0 for spectral type M5.0 and 9.5 for spectral type M9.5. Applying this relation results in estimated spectral types of M8.0±0.5 and M8.5±0.5 for component B and C, respectively.

The 5 Gyr K-band mass-luminosity relation of Baraffe et al. (1998) results in a mass 0.08±0.01 $M_\odot$ for component C. All three components have estimated masses close to the hydrogen-burning limit (Chabrier & Baraffe 1997), and the total mass of LP 714-37 is ∼0.28 $M_\odot$. Table 2 presents a summary of the derived physical parameters of the system.

3.2. Could LP 714-37 have formed through the ejection process?

Ejection models (Reipurth & Clarke 2001; Bate et al. 2002) suggest that (most) brown dwarfs form through the premature removal of pre-stellar cores from their parental molecular clouds by dynamical interactions. These models qualitatively predict that the binary brown dwarf systems that do exist must be close (separation ≤ 10 AU), since the small binding energy of wide BD binaries leaves them vulnerable to disruption. More recent simulations (Bate & Bonnell 2005) do produce some wide BD binary systems, when two unrelated objects are simultaneously ejected in the same direction. This mechanism however needs high density environments to work. It could thus not possibly form the wide binaries known in TW Hya, Cha I, and Upper Sco (Chauvin et al. 2004; Luhman 2004a, 2005). A caveat, however, is that some apparent binaries might be unresolved triple or higher order multiple systems, whose additional components could boost the binding energy of the systems enough to allow them to survive ejection.

Close et al. (2003) found that the minimum escape velocity in their sample of 34 VLM binaries is 3.8 km s^{-1} (Fig. 4). The escape velocity of LP 714-37 A and B at a 33 AU semi-major-axis would be $V_{\rm esc} \sim 3.3$ km s^{-1}, significantly under that limit. Accounting for the additional C component however increases the escape velocity of the system to 4.4 km s^{-1}. This is significantly above the 3.8 km s^{-1} (Close et al. 2003) empirical lower limit, and Figure 4 actually has a close analog of LP 714-37: GJ 1245ABC. LP 714-37 therefore demonstrates that some wide apparent VLM binaries are actually higher order multiple systems with $V_{\rm esc} \geq \sim 3.8$ km s^{-1} and no longer contradict the ejection scenario for brown dwarf formation. The wider VLM binaries identified by Martín et al. (2000), Billères et al. (2005), and Burgasser & McElwain (2006) however cannot be brought over $V_{\rm esc} \sim 3.8$ km s^{-1} for any realistic number of components. This suggests that other formation channels must exist, but a high resolution search for additional components among wide VLM binaries such as CFHT-Pl-18 (Martín et al. 2000), DENIS 0551-44 (Billères et al. 2005), and DENIS 2200−3038 (Burgasser & McElwain 2006) is clearly important.

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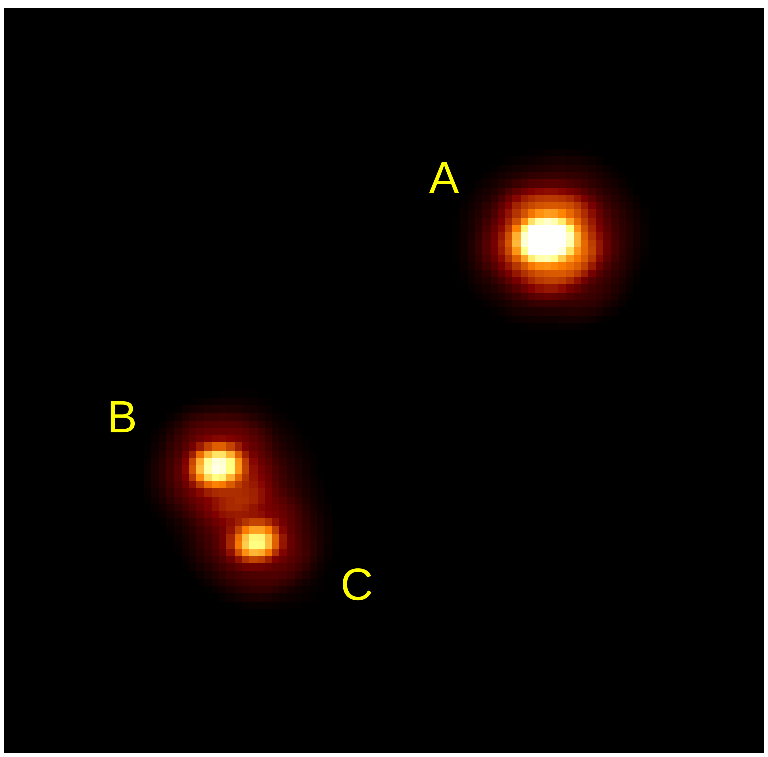

Fig. 1.— An adaptive optics image of LP 714-37 with CFHT in the K′ filter. The size of the image is 3.5″× 3.5″, and North is up and East to the left.

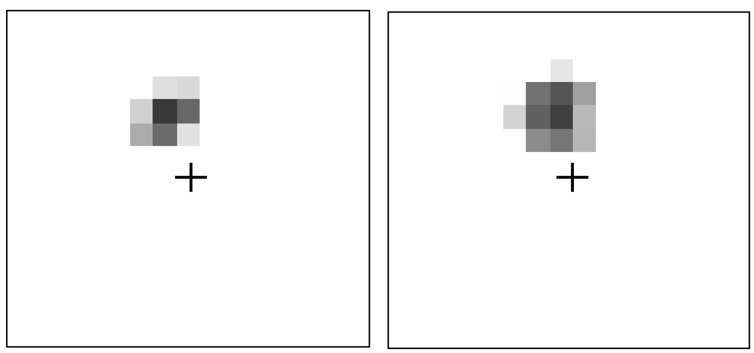

Fig. 2.— Archival images of the LP 714-37 system: 2MASS-K (left, epoch: 1998.690 from ALADIN) and DENIS-K (right, epoch: 2000.896). The cross indicates the position of component C at the 2005.784 epoch of the CFHT image. Component C would clearly be separated from LP 714-37AB in the 2MASS-K and DENIS-K images if it were not physically associated to the system. The size of each image is $15'' \times 15''$, and North is up and East to the left.

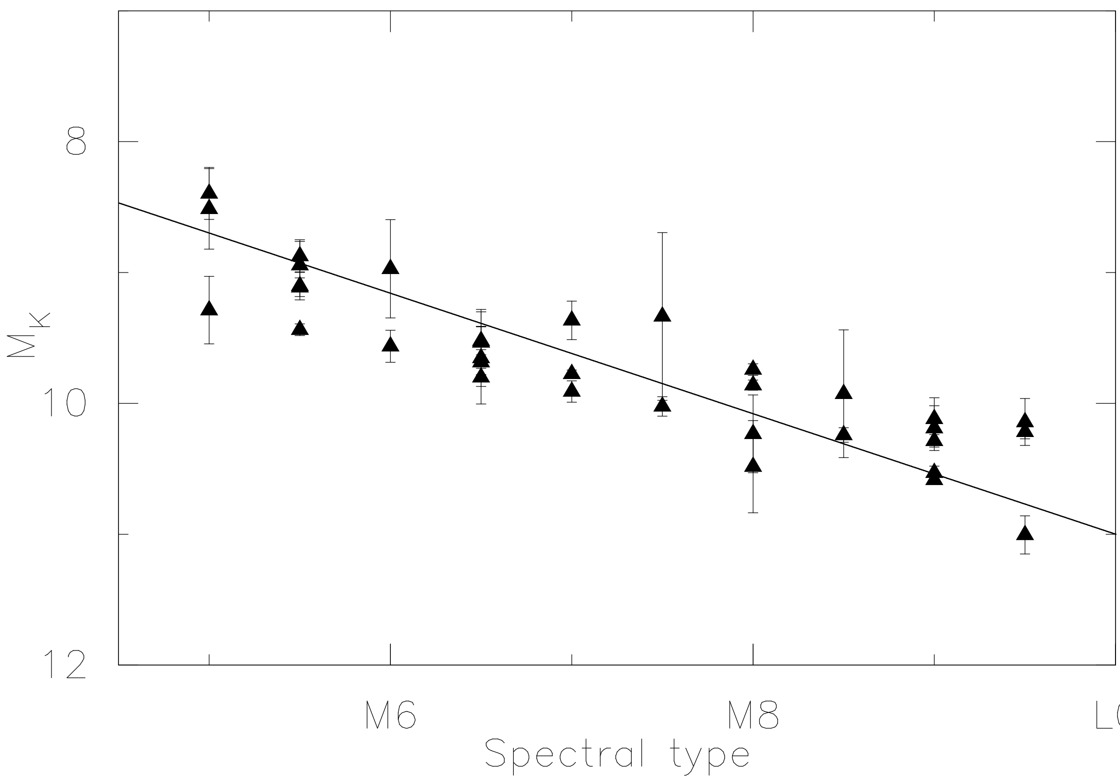

Fig. 3.— K-band absolute magnitude as a function of spectral type; most photometric data from Phan-Bao et al. (2003), Dahn et al. (2002); trigonometric parallaxes from van Altena et al. (1995), Monet et al. (1992), Dahn et al. (2002) and references therein.

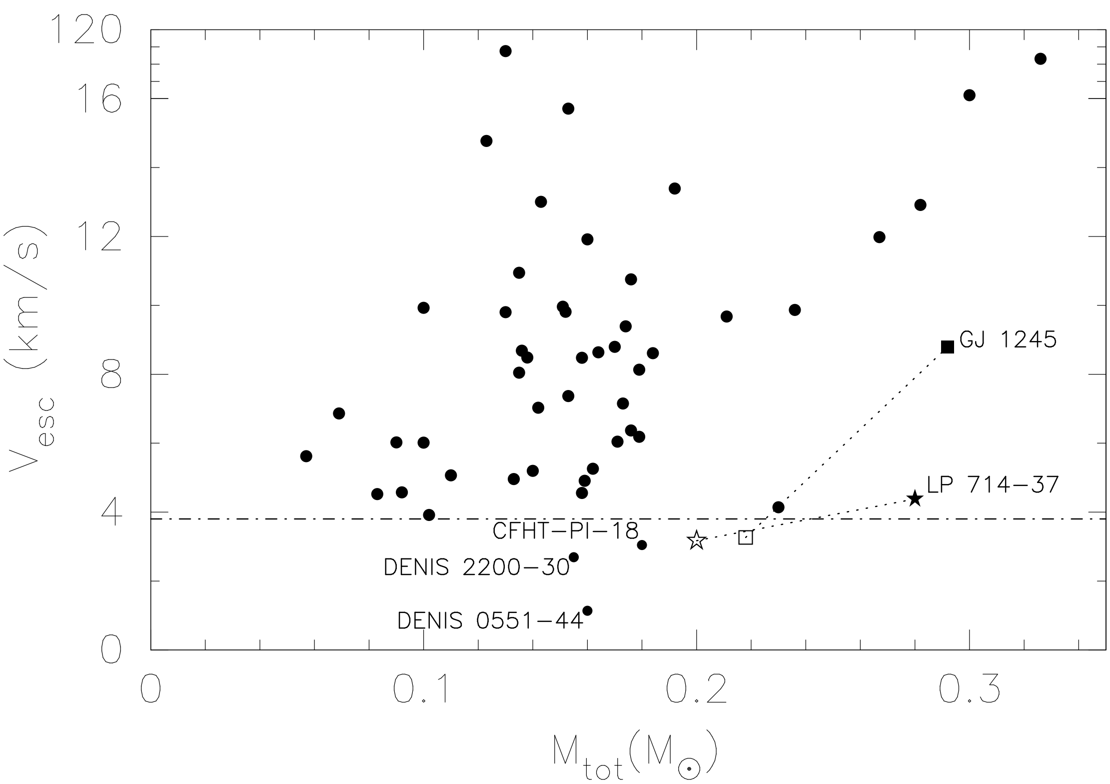

Fig. 4.— Escape velocity vs. total mass of the system for VLM systems in the field. The filled circles represent VLM binaries, from Siegler et al. (2005) and references therein; Reid & Gizis (1997); Beuzit et al. (2004); Martín et al. (2000); Billères et al. (2005); Burgasser & McElwain (2006). The squares show the VLM triple system GJ 1245; the empty square represents the escape velocity calculated by assuming the system would have only two components A and B meanwhile the filled square shows the escape velocity of the triple system. The LP 714-37 system is noted as different symbols (empty and filled star). Dash-dotted line: $V_{\rm esc} = 3.8$ km/s (Close et al. 2003).

Table 1: Relative astrometry and photometry of LP 714-37B and C relative to LP 714-37A.

Component	ρ (arcsec)	θ (deg)	$\Delta(K')$
LP 714-37B	1.87	124.9±0.5	0.94±0.05
LP 714-37C	1.96	135.4±0.5	1.24±0.05

Table 2: Spectral types of the three components of LP 714-37

Components	SpT	$M_{\rm K}$	Mass ($M_\odot$)
LP 714-37A	M5.5±0.5[1]	9.11±0.25[1]	0.11±0.01[1]
B	M8.0±0.5	10.05±0.30	0.09±0.01
C	M8.5±0.5	10.35±0.30	0.08±0.01

[1] : from Phan-Bao et al. (2005)

Column 1: Component name. *Column 2*: Spectral type, estimated from the $M_{\rm K}$ versus spectral type relation. *Column 3*: K-band absolute magnitude. *Column 4*: Mass determination for 1-5 Gyr from the models of Baraffe et al. (1998).